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Innovative Sandwiches for Civil Applications

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Abstract

Physics and mechanical tests were carried out on innovative sandwiches proposed for civil applications, at the aim to know their performances. The core was obtained by embedding short mineral fibre, in different percentages, in polyurethane matrix. The results of the experimental tests were compared to what obtained on sandwiches made without any reinforcement in the polyurethane core: better behaviours were found in terms of compression strength and elastic modulus, compression energy absorption capability, impact force and energy. Good results were observed in thermal conductivity too.

A very large experimental campaign was carried out at the aim to characterize the innovative sandwiches under shear load too. It was not simple to obtain the pure shear strength since the very frequent local compression failures due to the not uniform load distribution under bending tests. So, more than one kind of skin, wood, aluminium and polymeric one, was tested: a glass fibre laminate, 1,5 mm in thickness, was revealed the most appropriate one giving the possibility to have the right load distribution to observe the classical shear failure. Better behaviour was noted also in this field even if it resulted very dependent on the reinforcement percentages.

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1. Introduction

The interesting performances of mineral fibres, such as sound insulation properties, heat resistance, resistance to chemical attack, low water absorption and the improvement in production technology, lead to the innovative natural materials [1]. Moreover, the advantage to recycle wastes from the fragmentation of the mineral fibre under wool shape used for industrial applications had promoted, in the last years, the employment of natural fibres in polymer reinforcing [2-4].

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New perspectives have arisen on basalt fibre applications due to the potential low cost of this material together with its good mechanical performance, in particular at high temperature and to replace glass fibre industrial fields like aerospace, automotive, transportation and shipbuilding [5, 6].

The idea to fill these fibres into a polymer matrix is relatively recent and have not yet been sufficiently investigated in all the aspects [1-12]. The fibre–matrix interface, that could be a crucial point, has been studied in various basalt fibre–polymer matrix systems [7-12]. No information about the risk related to very low fibre diameters is known but, according to European law (97/69/Ce and 1907/2006) there should be no risk of toxicity since the fibre diameters is higher than 6 μm . Moreover, after burning the foam, it is very simple to recover and recycle them. The same does not happen for the glass fibres.

In this work, physics and mechanical tests were carried out on innovative sandwiches proposed for civil applications. The core was obtained by embedding short mineral fibre from industrial wastes, in different percentages, in polyurethane matrix. The influence of the reinforcement on the material response was verified. All the results obtained by the experimental tests were, then, compared to what obtained on sandwiches made without any reinforcement in the polyurethane core: better behaviours were found in terms of compression elastic modulus, compression energy absorption capability, impact force. In particular, about double higher value of the compression strength was observed.

2. Materials and test methods

Innovative sandwiches were fabricated by hand embedding short basalt fibre in rigid polyurethane matrix ESPAK “90”, 90 kg/m^3 , to obtain the core. Since the fibre adopted are wastes from the industrial process, the mechanical properties are unknown. The following weight percentages, 5%, 10%, 20%, 30%, 40% and 50% were considered at the aim to verify their influence on the material behaviour. For saturation reasons, it was not possible to fill more than 50% of fibre: dry fibre and a non homogeneous material were in fact observed. Since the difficulty in mixing the fibre and the matrix, more than one procedure, changing devices and materials, was tested at the aim to reduce the fabrication duration and to optimize the production technology and the quality of the final product. At the end, the mixture was dripped into a wood mould for only five minutes allowing to obtain specimens 20 mm in thickness. Simple circular specimens, 60 mm in diameter, were cut for compression and impact tests. Since the low sensitivity of the impact machine, for the dynamic tests, a polycarbonate layer, 1 mm in thickness, was necessary to add on both the surfaces as skin directly positioned on the foam during the polymerization.

Specimens with total nominal dimensions, length width and thickness, 230x40x20 mm, were destined to three points bending tests carried out on a support with a light of 150 mm. For the latter characterization, a research was started at the aim to obtain the right skin for the right load distribution under bending test. Skins in polyurethane, 2mm in thickness, wood and aluminium, 1 mm in thickness, in fact, were revealed not able since the concentrated load generating indentation (Fig. 1) on the loaded surface.



Fig. 1. Specimen indented under bending tests: skin in wood material.

Also the gluing phase to join skin and core was revealed crucial since the difficulty in obtaining a uniform distribution of the glue. Square glass laminates with about 50% of the fibre volume fraction were obtained manually overlapping four 0/90 E-glass fabrics, 290 g/mm² then they were impregnated with epoxy resin SX10 and polymerized under vacuum bag at 50°C for 24 hours. The final thickness of 1.5 mm was measured and the rectangular laminates cut from the square ones by a diamond saw were used as sandwich skins since, as shown hereafter, they allowed the good flexural load distribution and the determination of the right strength. Moreover, no glue was necessary to join the two parts of the final specimen.

Compression, bending and impact tests were carried out on the specimens to characterize the behaviour of the innovative sandwiches. ASTM D695-02a, ASTM D7250, EN6038 standards were followed respectively for the experimental tests. The Universal Machine MTS Alliance RT/50 was used for the experimental static campaign carried out at 6 mm/min. A falling weight apparatus, Ceast Fractovis MK4 was used for the dynamic impacts: the specimens, simply supported on a cylindrical support with an internal hole 50 mm in diameter were struck into the centre by a steel cylindrical impactor with a hemispherical nose 19.8 mm in diameter. Low velocity impact tests at about 4 m/s were carried out up to complete perforation of the material.

At the end, the thermal capability absorption was tested through thermal tests. The specimen made of the only core 20 mm in thickness was located on a ceramic square hot plate, 200 mm in side, at a constant temperature of 50°C, T_c , equipped with a temperature sensor and laterally insulated. On the free surface of the specimen, an aluminium plate 2 mm in thickness with an hole in which a thermocouple was inserted, was placed in order to measure the difference in temperature between the two surfaces. The thermal conductivity, k , in W/mK, was calculated through the following formula:

$$K = P \cdot \frac{d}{S} (T_c - T_f) \quad (1)$$

where P is the heat flow, 0,009020 W; d is the specimen thickness; T_c is the temperature of the surface in contact with the hot plate fixed at 50° C and constant for the whole test; T_f is the cold surface temperature, that is the same of the aluminium plate measured with the thermocouple; S is the square aluminium surface, 2 mm in side ($S=0,000324$ m²).

At the aim to make useful comparisons, all the tests were carried out also on similar specimens made by polyurethane without any reinforcement. At least five tests per each condition were carried out at the aim to verify the repeatability of the results.

3. Results

3.1 Compression tests

Fig. 2 shows the strength compression curves in the case of 20% of basalt in polyurethane matrix. All the other percentages and the single resin showed the same trend.

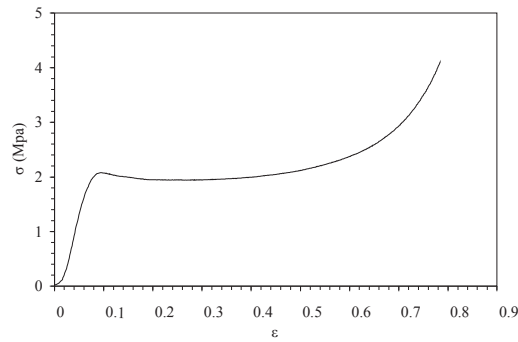


Fig. 2. Strength compression curve. 20% of basalt.

In the following graphs the results of the compression tests in terms of absorbed energy, maximum strength and young modulus, were reported. It is important to put in evidence the better behaviour of the reinforced material respect to the single resin in all the cases and for all the percentage values. Also the trend is quite similar: the maximum value of the analysed properties was obtained in correspondence of 5% of the basalt content. After that a decrease was observed up to 30% of the value followed by the higher value obtained for 40% but, except for the modulus, always lower than 5%. It means that it is not convenient to fill in the polyurethane more than a low fibre content that maybe is the right reinforcement over that it represent only an undesired discontinuity.

In Fig. 3, two different values of the compression energy were reported: looking at the typical load curve during compression tests, the first one, 50% of deformation, is obtained as the area under the curve (Fig. 2) up to $\epsilon = 0.5$ whereas the 70% value of deformation is in correspondence of the beginning of the increase in stiffness due to the final displacement of the compression plates.

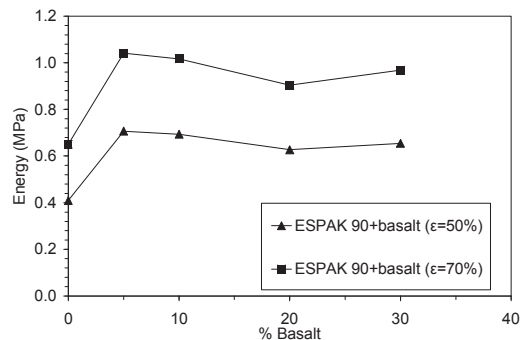


Fig. 3. Absorbed compression energy vs. basalt percentage.

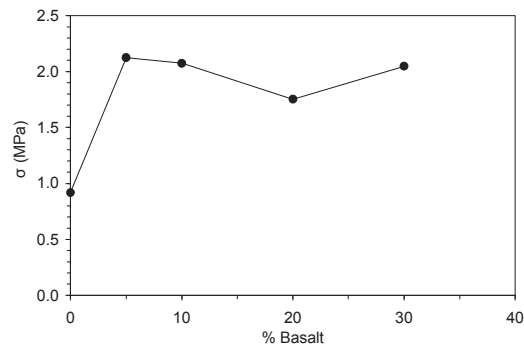


Fig. 4. Maximum compression strength vs. basalt percentage.

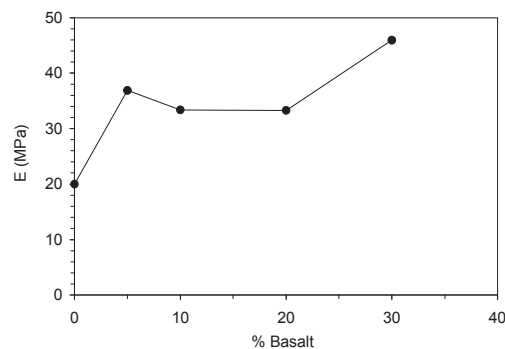


Fig. 5. Compression modulus vs. basalt percentage.

3.2 Shear properties by bending tests

At the aim to analyse the shear properties, bending tests were carried out on the selected sandwiches with the final selected skin in glass fibre reinforced plastic laminates. As already said, the latter allowed the right load distribution to observe the classical shear failure in the core called “shear crimping” in the sandwich configurations showed in Fig. 6.



Fig. 6. Failure under three points bending tests: shear crimping.

In Fig. 7, the characteristic maximum value of the shear strength value, τ_{\max} , was plotted against the basalt percentage.

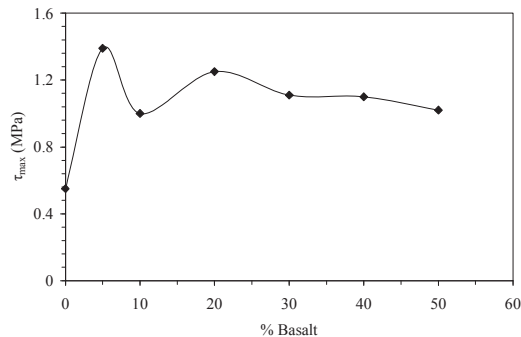


Fig. 7. Maximum shear strength vs. basalt percentage.

It is soon interesting to note a significant increase, more than double, of the shear strength respect to the single resin, in all the cases analyzed. Moreover, also in this case, the better behaviour was observed for 5% of the reinforcement. After that, a strange decrease when 10% of reinforcement was filled in was observed, followed by a constant trend.

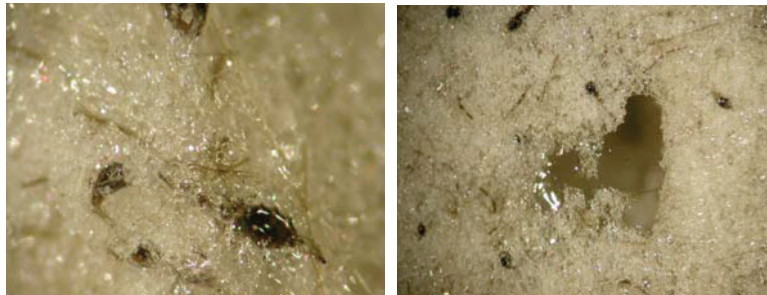


Fig. 8. Fractography images of a core section.

The lower values for higher percentages could be due to the difficulty in manual fibre impregnation. From the microscopy images about two sections of the same core and showed in Fig. 8, in fact, it is clear not only the difficulty in obtaining an homogeneous fibre distribution but also the presence of vacuum zone not possible to take under control during the manual fabrication.

To verify the influence of the mineral reinforcement percentage on the elastic shear modulus, G , in Fig. 9 the trend was reported.

The same considerations about the shear strength are valid here. In particular, respect to the polyurethane without any reinforcement, the sandwiches with 5% of mineral fibre showed an increase in modulus of about 160%. The lower value in correspondence of 10% of fibre confirms the validity of the previous trend observed in fig. 8 and rules out any thinks about errors.

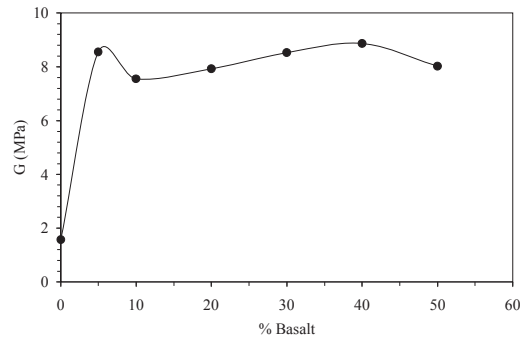


Fig. 9. Shear modulus, G , vs basalt percentage.

Since the density is a very important parameter in general for composite materials and in particular for sandwiches due to the foam core presence, this characteristic was measured in each condition adopted: as expected (Fig. 10) it linearly increases at increasing of fibre content.

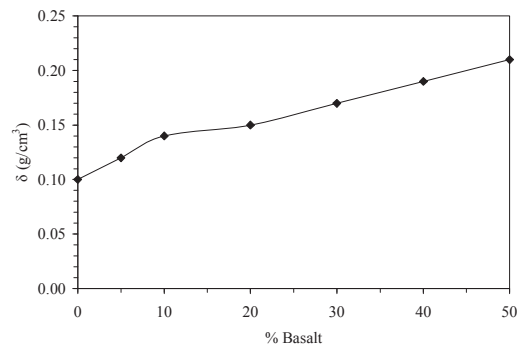


Fig. 10. Density, δ , vs % basalt percentage.

The same data of figures 8 and 9 were rearranged in figure 11 as a function of the material density.

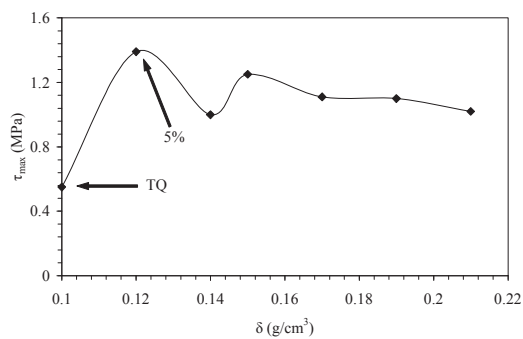


Fig. 11. Maximum shear strength, τ_{max} , vs material density, δ .

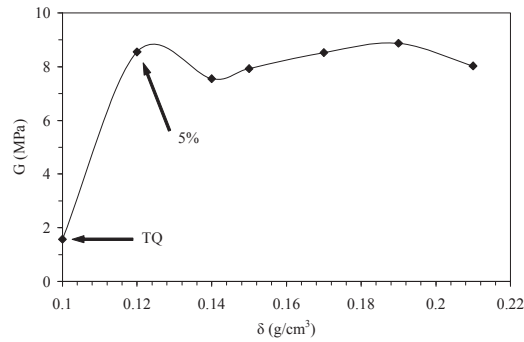


Fig. 12. Shear modulus, G , vs. material density, δ .

The graphs show that it is not convenient a core with more than 5% of fibres since after that value an increase of weight without any sensible improvement in mechanical properties was observed, confirming what found analyzing compression tests. So, it is possible to obtain the maximum increase in performances through a minimum fibre impregnation even if it is not possible to neglect the effect of the manual technology.

3.3 Impact tests

In fig. 13 a typical Force–displacement curve recorded during an impact test on the sandwich with polycarbonate skin described in above paragraph, was showed. It is possible to note the classical trend of similar tests on composite materials [13] where an increase up to a maximum load, arrow 1 in figure, followed by a decrease denoting lost in resistance due to damage start and propagation, was evidenced. The second load peak, arrow 2, is here due to the presence of polycarbonate sheet also on the opposite side respect to the impacted one, to penetrate it a higher force is necessary.

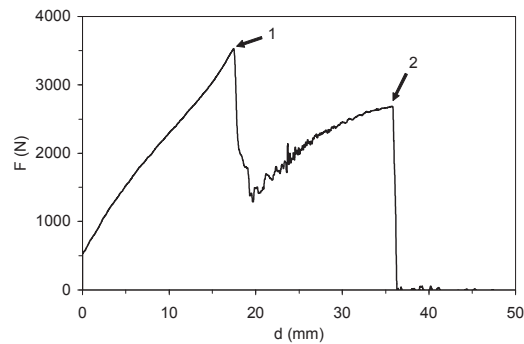


Fig. 13. Impact load curve, 20% of basalt fibre.

In fig. 14, the influence of the mineral fibre was reported on the maximum force: also here a better behaviour of the reinforced material was confirmed with an increasing trend.

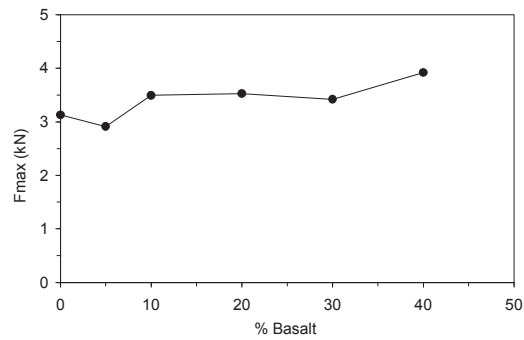


Fig. 14. Maximum impact force vs. fibre percentage.

It is, however, not confirmed what happened in static tests about the 5% of the filler. This happens also for the maximum impact energy, the area under load curve up to maximum force, showed in Fig. 15.

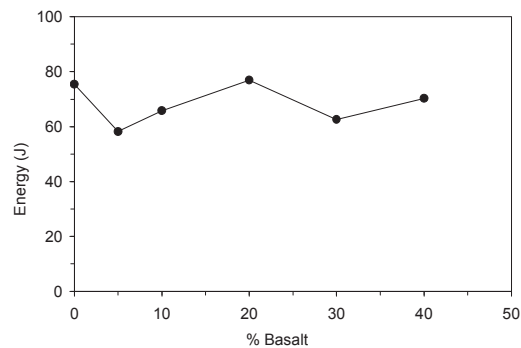


Fig. 15. Maximum impact energy vs. fibre percentage.

3.4 Thermal tests

The thermal absorption coefficient obtained by equation 1, was plotted against the basalt content percentage in Fig. 16.

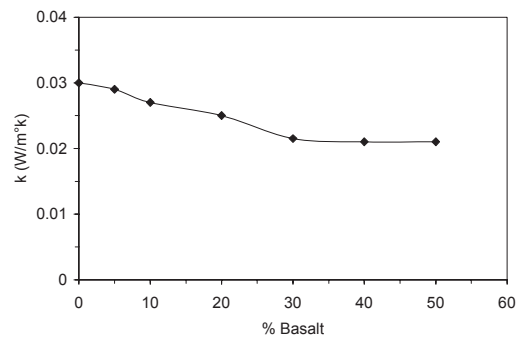


Fig. 16. Thermal absorption coefficient vs basalt fibre content.

A decreasing trend was observed starting from the resin: with the increasing of the fibre content a better insulating behaviour of the material was noted.

1. Conclusions

Mineral basalt fibre were filled in polyurethane rigid resin and the specimens were tested under static and dynamic load conditions. In all the analyzed cases a better behaviour of the innovative composite respect to the matrix was obtained. Moreover, the possibility to reach higher performances with a minimum of the fibre filled in the resin was evidenced. From physics tests, a good behaviour as insulator was noted together with an increase in performances at the increasing of the reinforcement. At the end, the good interaction between natural fibre and polyurethane improve the behaviour of the foam.

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